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The Flow of Plasma in the Solar Terrestrial Environment

Semiannual Status Report

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During the reporting period, we submitted 9 papers for publication and presented 1 review talk at a scientific meeting. The papers and review talk are listed below, and abstracts of the papers are attached.

The papers are in the areas of plasma expansion phenomena, the polar wind, and auroral plasma processes. In one paper, we studied the development of electric fields in an expanding plasma (paper 4). These electric fields accelerate ions to suprathermal energies and are similar to those in double layers with a zero current. With regard to the polar wind, we showed that hot magnetospheric electrons (polar rain, polar showers, and polar squall) have a pronounced effect on the polar wind (paper 1). These hot electrons act to increase the H^+ outflow velocity and energy, with the energy gain being as large as 1 to 2 keV. We also showed that, contrary to previous predictions, there is no O^+ charge exchange barrier and substantial fluxes of O^+ ions can escape with the polar wind (paper 3).

In the auroral plasma physics area, we studied the excitation of electrostatic waves by field-aligned auroral electron beams (paper 2). We also showed that the auroral field-aligned current density can be large enough to excite Buneman double layers (paper 5). For situations that lead to strong double layers, we showed that the temporal evolution of the potential profile is controlled by current fluctuations (paper 6). In addition, we conducted two-dimensional particle-in-cell simulations and studied the high frequency wave turbulence excited by an auroral electron beam of finite width perpendicular to an ambient magnetic field (paper 7), and we studied the formation of V-shaped auroral potential structures (paper 8). Finally, we wrote a review article on numerical simulations of double layers and auroral electric fields (paper 9).

Presentations

R.W. Schunk, A Global Ionospheric Model, Invited Review, Presented at the "Optical Ground-Based Aeronomy Workshop II", June 20-22, 1984; Ann Arbor, Michigan.

Papers Submitted

1. A.R. Barakat and R.W. Schunk, Effect of hot electrons on the polar wind, J. Geophys. Res., 89, 9771-9783, 1984.

2. N. Singh, J.R. Conrad and R.W. Schunk, Electrostatic ion cyclotron, broadband and lower hybrid waves excited by an electron beam, J. Geophys. Res., in press.

3. A.R. Barakat and R.W. Schunk, O^+ charge exchange in the polar wind, J. Geophys. Res., 89, 9835-9839, 1984.

4. N. Singh and R.W. Schunk, The relationship between the electric fields associated with plasma expansion and double layers, Proceedings of the Second Symposium on Plasma Double Layers and Related Topics, 272-277, 1984.

5. N. Singh and R.W. Schunk, Can Buneman double layers be driven in auroral plasmas?, Proceedings of the Second Symposium on Plasma Double Layers and Related Topics, 364-369, 1984.

6. N. Singh, H. Thiemann and R.W. Schunk, Current fluctuations and dynamical features of double layer potential profiles, Proceedings of the Second Symposium on Plasma Double Layers and Related Topics, 278-283, 1984.

7. H. Thiemann, N. Singh and R.W. Schunk, High frequency turbulence in a plasma driven by a current sheet, Proceedings of the Second Symposium on Plasma Double Layers and Related Topics, 315-320, 1984.

8. H. Thiemann, N. Singh and R.W. Schunk, Some features of auroral electric fields as seen in 2D numerical simulations, Advances in Space Research, in press.

9. N. Singh, R.W. Schunk and H. Thiemann, Numerical simulations of double layers and auroral electric fields, Advances in Space Research, in press.

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Effect of Hot Electrons on the Polar Wind

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Submitted to

J. Geophys. Res.

January, 1984

Abstract

A semikinetic model was used to study the effect that hot electron populations have on the polar wind. The model was used to describe the steady state plasma flow along diverging geomagnetic field lines in the collisionless regime at high altitudes. The plasma contained O^+ and H^+ ions and both hot and cold electron populations. Several hot electron populations were considered, including the polar rain, polar showers, and polar squall. Estimates of hot electron parameters based on characteristic energy and flux measurements indicate that the hot/cold electron temperature ratio varies from $10 - 10^4$ and that the percentage of hot electrons varies from 0.1% to 10% at 4500 km. For ratios at the lower ends of these ranges, the polar wind solutions with hot electrons are similar to those obtained previously for supersonic H^+ outflow without hot electrons. For higher hot electron temperatures and a greater percentage of hot electrons, there is a discontinuity in the kinetic solution, which indicates the presence of a sharp transition. This transition corresponds to a contact surface between the hot and cold electrons. Along this surface, a double layer potential barrier exists, which reflects the cold ionospheric electrons and prevents their escape. The presence of the hot electrons acts to increase the supersonic H^+ outflow velocity and H^+ energy, but does not affect the already saturated H^+ escape flux. The H^+ energy gain may be as large as 1 to 2 keV. With regard to O^+, the hot electrons act to reduce the potential barrier, thereby allowing more O^+ ions to escape. A significant enhancement in the O^+ escape flux can occur depending on the hot electron density and temperature.

Electrostatic Ion-Cyclotron, Beam-Plasma and Lower Hybrid Waves Excited by an Electron Beam

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Submitted to JGR

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Abstract

The excitation of waves at frequencies $\omega < \omega_{\ell h}$, where $\omega_{\ell h}$ is the lower hybrid (ℓH) frequency, by a low energy electron beam is examined under the electrostatic approximation; the frequency range $\omega < \omega_{\ell h}$ includes the ion-cyclotron frequencies (Ω_i) and their harmonics in a multi-ion plasma. Since the beam velocity $V_b >> v_{te}$, the electron thermal velocity, the excited waves have phase velocities $V_p \approx V_b >> v_{te}$. Thus, the background electrons can be treated as cold and the electron density fluctuations are small. In the limit of cold ion approximation, the excited waves are either the ion-cyclotron resonance cone (ICRC) waves or the beam-plasma (b-P) mode. Both of these waves show stop bands near the gyrofrequencies of the constituent ions. The ICRC waves are limited to the highest gyrofrequency while the B-P mode propagates even beyond it. A comparison of the characteristics of the electrostatic ICRC waves with those determined from a full electromagnetic (FEM) treatment at frequencies $\omega < \Omega_i$ shows that the electrostatic approximation is valid when beam energy is low (~100eV) and for relatively more energetic beams the validity holds good only when the perpendicular wave number $k_\perp$ is sufficiently large ($k_\perp > 10^3 \Omega(H^+)/C$, Ω being the H^+ gyrofrequency, and C the velocity of light in vacuum). Warm ion effects on the waves are examined; when $K_\perp = k_\perp r_\ell(H^+) > 0.3$, where $r_\ell(H^+)$ is the H^+ Larmor radius in a He^+-H^+ plasma, the excited waves are the EIC waves. Because of their phase velocity $V_p >> v_{te}$, these EIC waves are pure ion-Bernstein (PIB) waves. The characteristics of the electron-beam excited PIB waves are compared with their counterpart, the neutralized ion-Bernstein (NIB) waves, which are EIC waves excited by drifting bulk electrons. The consideration of electrostatic waves in the frequency band $\Omega(H^+) < \omega < \omega_{\ell h}$ shows that the B-P waves with

$k_{\perp} r_{\ell}(H^{+}) \ll 1$ have considerably larger temporal growth rates than the EIC waves. The interconnections between LH and B-P waves are found to be similar to those between EIC and B-P waves; B-P waves have long perpendicular wavelengths ($\lambda_{\perp}$) while EIC and LH waves have comparatively much shorter ones. The relevance of ICRC and PIB waves to satellite observations of waves in the ELF band is discussed. The B-P waves appear to be similar to the electrostatic broadband noise (BEN) emissions in the frequency range from below the ion-cyclotron frequency to the lower hybrid frequency observed from various satellites in the auroral and cusp regions.

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O^+ Charge Exchange in the Polar Wind

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Abstract

The continuity and momentum equations for ionospheric O^+ were solved for typical polar cap conditions. Density profiles were obtained both with and without allowance for accidentally-resonant charge exchange (ARCE) between O^+ and H. It was found that ARCE acts to reduce the maximum (or limiting) O^+ escape flux by less than 30% for typical atmospheric conditions ($T_\infty \gtrsim 1000$ K) and by only a factor of about 3.5 for atmospheres with low exospheric temperatures ($T_\infty = 750$ K). With allowance for ARCE the limiting O^+ escape flux is of the order of 5×10^8 to 10^9 cm^{-2} s^{-1}, depending on the atmospheric conditions, which easily accounts for the existing measurements. This indicates that, contrary to previous predictions, there is no O^+ charge exchange barrier, and consequently, it is not necessary to have an acceleration mechanism at low altitudes in order to have an appreciable O^+ escape flux. Instead, an O^+ depletion at high altitudes due to some acceleration mechanism is sufficient to cause large O^+ fluxes to escape from the ionosphere to the magnetosphere.

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THE RELATIONSHIP BETWEEN THE ELECTRIC FIELDS ASSOCIATED WITH PLASMA EXPANSION AND DOUBLE LAYERS

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The phenomenon of plasma expansion occurs in a variety of situations ranging from laser fusion to space physics. It is now believed that plasma expansion plays an important role in the electrodynamics of the wake of bodies in plasmas. In space plasmas, these bodies can be either man-made or natural objects, such as the terrestrial moon and planets, etc. The phenomenon of plasma expansion has been found to be relevant to the initial expansion of the polar wind and to interhemispheric plasma flows. An important characteristic of a plasma expansion is the development of polarization electric fields, which can be localized. These electric fields accelerate ions to suprathermal energies. Since the electrons and ions in the expansion drift with equal velocities, there is no net current. Thus, the localized electric fields associated with expanding plasmas are like double layers with a zero current. These double layers move with the expanding plasma front. The characteristics of the localized electric fields in both single and multi-ion plasma expansions, as seen from numerical simulations, will be presented. These characteristics will be compared with those of classical double layers with currents.

CAN BUNEMAN DOUBLE LAYERS BE DRIVEN IN AURORAL PLASMAS?

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Results from both one-dimensional numerical simulations and space measurements on the magnitude of the field-aligned currents will be presented to show that Buneman double layers can be driven on auroral field lines. The temporal evolution of the current density and electric field will be used to show the various stages leading to the formation of double layers. The current density in the plasma displays a cyclic interruption and recovery. The Buneman instability is triggered during current recovery. The current interruption occurs along with the double layer formation, which is also cyclic. Some dynamical aspects of Buneman double layers will be discussed. It will be shown that when the current through the plasma is relatively large, a common feature of the turbulence on the high potential side of the double layers is the formation of electron holes. On the other hand, when the current drops below the thermal current, a localized potential dip forms on the low potential end of the Buneman double layers.

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CURRENT FLUCTUATIONS AND DYNAMICAL FEATURES OF DOUBLE LAYER POTENTIAL PROFILES

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The low frequency oscillations caused by potential relaxation instabilities (PRI) occurring in one-dimensional simulations of strong double layers and the accompanying formation of potential dips on the low potential end of the double layers is reviewed. Two-dimensional (2-d) numerical simulations of double layers in a magnetized plasma show oscillations in the current caused by both PRI and electrostatic ion cyclotron (EIC) waves. During current troughs, the double layers tend to develop localized dips at the low potential end of the parallel profiles, and their strength tends to increase. The occurrence of potential dips in association with current interruptions in very diverse situations shows that such a feature is universal.

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HIGH FREQUENCY TURBULENCE IN A PLASMA DRIVEN BY A CURRENT SHEET

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High frequency ($\omega \sim \omega_{pe} < \Omega_e$) wave turbulence excited by an electron beam of finite width perpendicular to an ambient magnetic field in a background plasma is described. The results discussed here are from a 2 1/2-dimensional numerical simulation with a plasma bounded in the direction of the current flow and unbounded with the periodic boundary condition in a direction transverse to it. During the early stages of the beam-plasma interaction a very intense turbulence occurs, which eventually disrupts and at a late stage a quasi-steady state with an appreciable level of turbulence follows. The high frequency turbulences undergo considerable modulations by various low frequency phenomena. Although the electron current is limited to a narrow channel, the waves excited by the current spreads efficiently outside the channel.

SOME FEATURES OF AURORAL ELECTRIC FIELDS AS SEEN IN 2D NUMERICAL SIMULATIONS

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ABSTRACT

Results of 2D plasma simulations, which show the formation of V-shaped double layers with larger perpendicular than parallel electric field amplitudes, the excitation of electrostatic ion-cyclotron waves and the occurrence of return currents, are presented and related to auroral observations.

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NUMERICAL SIMULATIONS OF DOUBLE LAYERS AND AURORAL ELECTRIC FIELDS

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ABSTRACT

Recent numerical simulations on double layers (DL) are reviewed and discussed in the light of relevant space observations in the auroral plasma. Two-dimensional (2-d) DLs driven by current sheets of a finite thickness ℓ show different characteristics depending on whether $\ell < \rho_i$ or $\ell \gg \rho_i$, ρ_i being the ion gyroradius. In the former case, V-shaped DLs form with nearly equal parallel and perpendicular potential drops ϕ_n, which are determined by the temperatures of the various constituent ions. In the latter case, the major parallel potential drop occurs outside the current sheet and the perpendicular electric fields are localized at the edges of the current sheet. Some important features, such as the amplitudes and scale lengths of the parallel and perpendicular electric fields, seen in these simulations are qualitatively similar to those observed in space. The review of one-dimensional simulations covers the following: (i) The dynamical features of DLs and their possible applications to flickering auroras and low frequency fluctuations of inverted-V events; (ii) Ion-acoustic double layers with sustained currents and their relationship to weak DLs observed in auroral plasmas; (iii) Recent DE observations of large field-aligned currents (> 100 $\mu A/m^2$) and the excitation of Buneman double layers.